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CHARTS FOR THE PARAMETERS OF
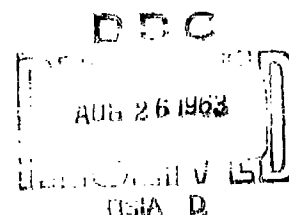MIGRATING EXPLOSION BUBBLES

NOL

15 OCTOBER 1962

UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

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CHARTS FOR THE PARAMETERS OF MIGRATING EXPLOSION BUBBLES

By

H. G. Snay and Ruth V. Tipson

ABSTRACT: Graphs are presented for the relative bubble energies, maximum radii, periods, and migrations of underwater explosion bubbles for four cycles of the bubble oscillation. The migration refers to the bubble maximum in each cycle. The position of the bubble minimum can be readily found by a simple computation. The graphs permit a convenient reading of these parameters for a wide range of conditions.

PUBLISHED SEPTEMBER 1963

CHARTS FOR THE PARAMETERS OF MIGRATING EXPLOSION BUBBLES

This report is part of a comprehensive study on the behavior of explosion gas bubbles which has been carried out under Task No. 301-664/43003/01040 and RUME-3-E-000/212-1/WF 008-10-004 PA 002. A knowledge of the behavior of migrating gas bubbles is of considerable importance in studies of ship damage. NAVORD Report 3906, "Key Problems in Explosive Research and Development", Chapter III, "Anti-Submarine Warfare" discusses this in more detail. The present report represents a numerical evaluation of the theory developed in NAVORD Report 4185. The charts prepared on the basis of this theory provide a simple method which this Laboratory believes will save considerable time and effort in calculating the important characteristics of explosion bubbles in the second and subsequent cycles of the pulsation.

The major portion of this work was carried out during a course of duty of the second author as a junior professional trainee.

R. E. ODENING
Captain, USN
Commander

C. J. ARONSON
By direction

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ILLUSTRATIONS

I. INTRODUCTION

In NAVORD Report 4185* relationships are derived for the migration and energy ratios of underwater explosion bubbles. The data given in that report are sufficient to provide the information needed for calculating the migration period, maximum radius, and energy through the 4th cycle. In the present report this information has been used to make graphs for the ratios of these parameters. The use of non-dimensional variables permits the convenient reading of the results for a wide range of explosive conditions.

II. THE EQUATIONS OF MIGRATING BUBBLES

The equation for the migration for pulsating bubbles between the nth and (n + 1)th bubble maximum derived in NAVORD Report 4185 (Equation 9) can be written in the following form

$$\frac{Z_n - Z_{n+1}}{Z_1} = \frac{\Delta Z_n}{Z_1} = C \left(\frac{A_{M1}}{Z_1} \right)^{3/2} \left(\frac{r_n}{r_1} \right)^{1/2} \frac{Z_1}{Z_n} \left[1 - 0.1 \frac{A_{M1}}{Z_1} \left(\frac{r_n}{r_1} \right)^{1/3} \left(\frac{Z_1}{D_n} \right)^{2} \left(\frac{Z_n}{Z_1} \right)^{2/3} \right] ,$$

(1)

where

Z = Total hydrostatic pressure measured in feet of water.
1 atmosphere = 33 ft sea water = 34 ft fresh water

A_M = Maximum bubble radius in ft.

r = Ratio of bubble energy to the total energy of explosion.

n = Subscript designating the cycle of the pulsation.

D = Depth in ft below the water surface. D refers to the center of the bubble maximum. In the first cycle, D_1 is assumed to be equal to the depth of explosion, i.e. the migration up to the first bubble maximum is neglected.

* Full reference is given at the end of this report.

It is stated in NAVORD 4185 that C can be considered to be a universal constant, C = 3.5.

From (1) it appears that $\Delta Z_n/Z_1$ is a function of A_{M1}/Z_1, Z_n/Z_1, D_n/Z_1 and r_n/r_1. The energy ratio r_n/r_1 is evaluated in NAVORD 4185 and is shown to be a function of $\Delta Z_n/Z_n$. The two variables Z_n/Z_1 and D_n/Z_1 are functions of the reduced migration $\Delta Z_n/Z_1$, as can be seen in the following relations:

$$\frac{Z_n}{Z_1} = \frac{Z_{n-1}}{Z_1} - \frac{\Delta Z_n}{Z_1} \tag{2}$$

and $\qquad\qquad\qquad\qquad n = 2, 3, \ldots$

$$\frac{D_n}{Z_1} = \frac{D_{n-1}}{Z_1} - \frac{\Delta Z_n}{Z_1}. \tag{3}$$

Therefore, the reduced migration and the depths of the later bubble maxima are functions of two variables only, namely A_{M1}/Z_1 and D_1/Z_1. This fact permits a convenient graphical representation not only of the migration, but also of the other bubble parameters.

The equation for the first maximum bubble radius is, reference (b),

$$A_{M1} = J \left(\frac{W}{Z_1} \right)^{1/3}, \tag{4}$$

where

W = Charge weight in lbs,

J = Radius constant dependent on the properties of the explosive, e.g. J = 12.6 for TNT, reference (c).

The maximum radius at any one of the subsequent cycles is given by

$$\frac{A_{Mn}}{A_{M1}} = \left(\frac{r_n}{r_1} \frac{Z_1}{Z_n} \right)^{1/3}, \text{ (NAVORD 4185, Equation 4).} \tag{5}$$

The period of the first bubble pulsation for an explosion in infinitely deep water is, reference (b),

$$T_1 = K \frac{W^{1/3}}{Z_1^{5/6}} \left[1 - 0.1 \frac{A_{M1}}{D_1} \right] , \qquad (6)$$

where K is the period constant, e.g. K = 4.36 for TNT, reference (c). The term $0.1 A_{Mn}/D_n$ accounts for the effect of the water surface on the pulsation. It is negligibly small for a deep explosion, but compensates for the shorter periods of a bubble pulsating near the water surface. (Compare Section III of NAVORD 4185 about the value 0.1.)

The periods of the subsequent cycles can be obtained from

$$\frac{T_n}{T_1} = \left(\frac{r_n}{r_1} \right)^{1/3} \left(\frac{Z_1}{Z_n} \right)^{5/6} \frac{1 - 0.1 A_{Mn}/D_n}{1 - 0.1 A_{Mn}/D_1} , \qquad (7)$$

as discussed in NAVORD 4185, Equation (2).

Since (5) and (7) contain only parameters which are functions of A_{Mn}/Z_1 and D_1/Z_1, the period and radius ratios are functions of these two variables only and each can be graphically presented by means of a family of curves.

For shallow explosions, the presence of the water surface perturbs the bubble oscillation in such a way that the emission of the bubble pulse ceases. This phenomenon is commonly called venting of the bubble or blow-in. It can be quantitatively taken into account using the evidence that the nth bubble pulse will not occur when

$$A_{Mn} \leq 1.1 \, D_n . \qquad (8)$$

III. NUMERICAL CALCULATIONS

The calculations of this paper are based on the relationships listed above and the values of r_n/r_1 found in NAVORD Report 4185. The ratios for the depths of the bubble maximum, the periods, the maximum radii, and the bubble energies were calculated for the first four cycles of the oscillation. In view of the uncertainty of the energy ratio for the 5th cycle, given in NAVORD 4185, this case was not included. Graphs were made using A_{M1}/Z_1 as abscissas and the above bubble parameters as ordinates. The result is presented as a family of curves each labelled by a value D_1/Z_1.

Limiting curves were constructed for the condition where blow-in occurs, Figures 1 to 3. In the other charts the points of blow-in are marked. The continuation of the curves beyond these points is shown in dashed lines. They are useful for certain calculations, although for such conditions no bubble pulse occurs.

IV. USE OF THE GRAPHS

Given the weight of the explosive charge W and the depth D_1 at which it is fired, one uses the formulae

$$\frac{D_1}{Z_1} = \frac{D_1}{D_1 + 33} \tag{9}$$

$$\frac{A_{M1}}{Z_1} = J \frac{W^{1/3}}{Z_1^{4/3}} \tag{10}$$

to find the input of the charts. The ratios read from the graphs are multiplied with the value of the corresponding variable for the first cycle of the oscillation. This immediately yields the desired result.

As an example suppose one desires to know the depth of the third bubble maximum of a 290-lb TNT charge fired at a depth of 150 ft in sea water. Here, Z_1 = 150 ft + 33 ft = 183 ft. Using (10) one finds A_{M1}/Z_1 = 0.0803 and from (9) D_1/Z_1 = 0.82. The first period is according to (6) T_1 = 0.372. Using these values one finds from Figure 2: D_3/D_1 = 0.830 and D_3 = 125 ft. Thus, the upward migration of the bubble from the initial charge location up to the moment of the third bubble maximum has been 25 ft. In an analogous way one finds from Figure 5: T_3/T_1 = .75, and T_3 = 0.279 seconds. The period T_3 refers to the time between the second and third bubble minimum. The time of the third maximum would be $T_1 + T_2 + T_3/2$ = 0.834 seconds. The position of the third bubble minimum can be found by calculating that of the fourth bubble maximum and placing the bubble minimum half way between these two maxima.

V. COMMENTS ON THE DEPENDENCY OF THE BUBBLE PARAMETERS ON THE EFFECT OF THE WATER SURFACE

Inspection of the graphs presented in this report gives an interesting insight on the influence which the two input variables have on the bubble behavior.

The magnitude A_{M1}/Z_1 is a measure of the buoyancy of the bubble. The maximum radius used in this ratio represents the pressure difference between bubble top and center. It is this type of pressure difference which, when integrated over the bubble surface, produces buoyancy. Z_1 stands for the total pressure at the bubble center. Hence, A_{M1}/Z_1 represents one-half of the pressure difference between bubble top and bottom divided by the pressure at the center. This magnitude accounts for the driving force of the gravity migration.

The other variable, D_1/Z_1, is a measure of the depth at which the explosion occurs. The deeper the explosion, the closer is this value to unity.

Comparing the above equations, it is seen that D_1/Z_1 occurs in the surface correction terms only. Hence, A_{M1}/Z_1 is a measure of the strength of migration, and D_1/Z_1 is a measure of the surface effect.

The graphs illustrate the importance of these two effects on the bubble parameters. Figures 1 to 3 represent the migration. The large spread of the family of curves in this figure indicates that the surface effects have a strong bearing on migration. The influence is less pronounced for the bubble periods, Figures 4 to 6, but still clearly noticeable. This evidence was to be expected, since equations (1) and (6) include surface correction terms. But, the surface effect also enters into the computation of the maximum bubble radius and the bubble energy, although these terms are not directly affected by the water surface. The curves for the maximum radii, Figure 7, show this influence only for close proximities of the bubble to the water surface: The curve for each reduced depth D_1/Z_1 emerges from the average curve near the point of blow-in or for very shallow conditions. The same effect is noticeable for the bubble energy ratio, Figure 8.

This discussion illustrates the importance of the surface effect and shows that it must not be neglected in a study of bubble migration. The charts presented in this paper quantitatively account for this effect and, at the same time, allow for a convenient appraisal of its significance. For instance maximum radius, bubble energy, and periods depend mainly on A_{M1}/Z_1. On this basis, simple approximate formulae could be set up which give these magnitudes as functions of A_{M1}/Z_1 only. The charts illustrate the limited accuracy of such approximations. Since reading of a graph is simpler than to evaluate equations, we have not included such formulae in this report.
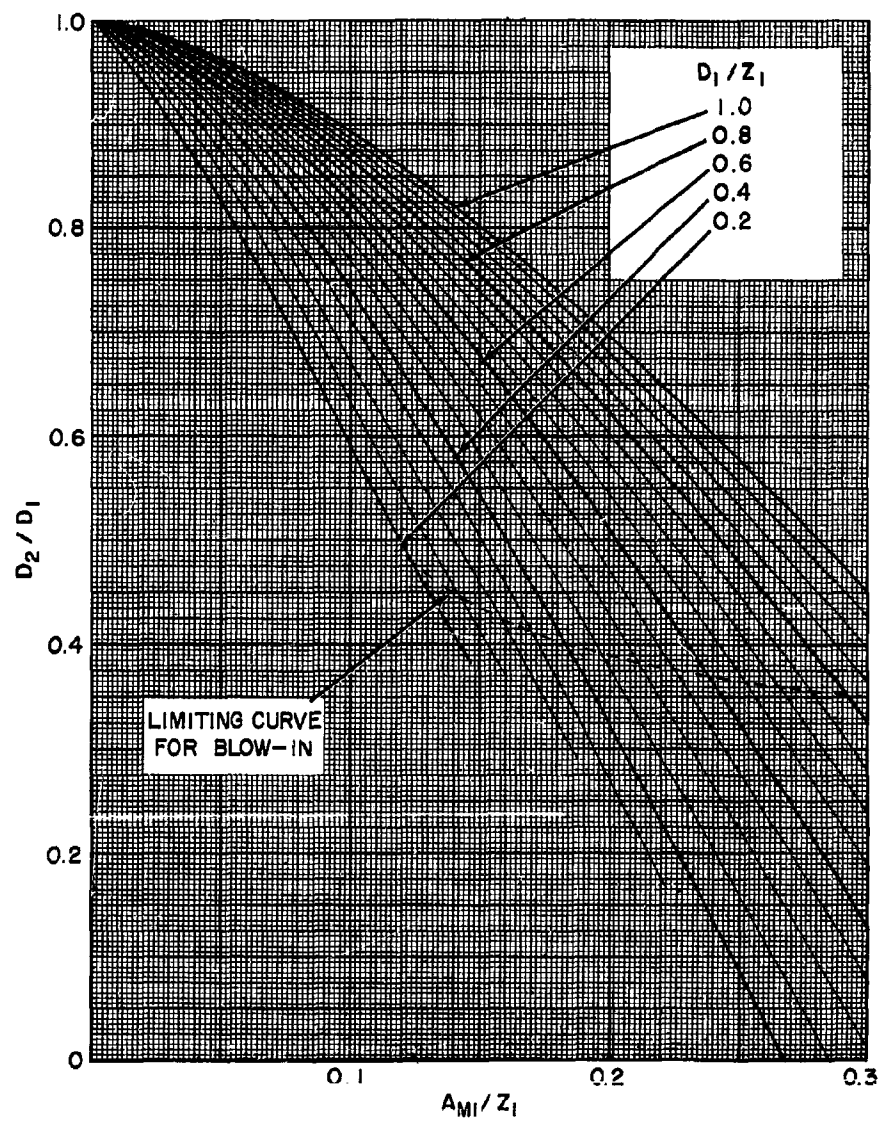
FIG.I RELATIVE DEPTH AT SECOND BUBBLE MAXIMUM
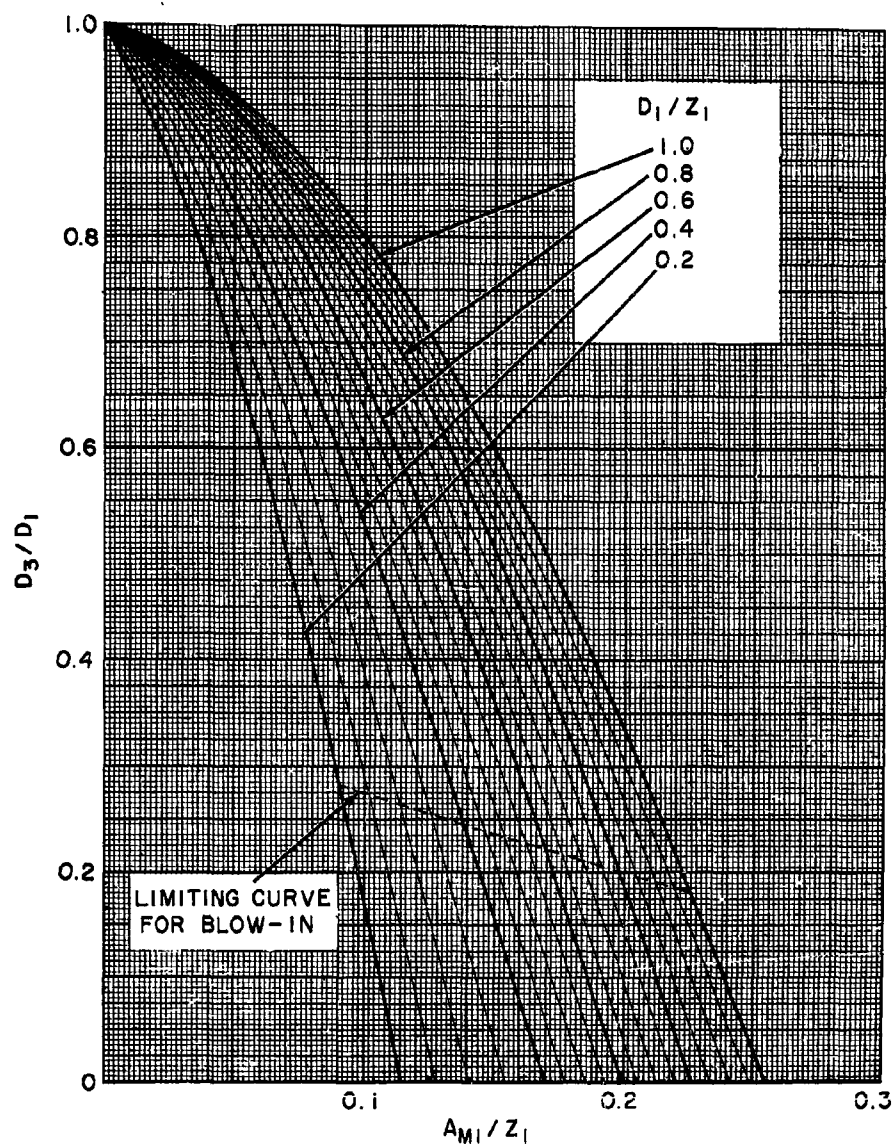
FIG. 2 RELATIVE DEPTH AT THIRD BUBBLE MAXIMUM
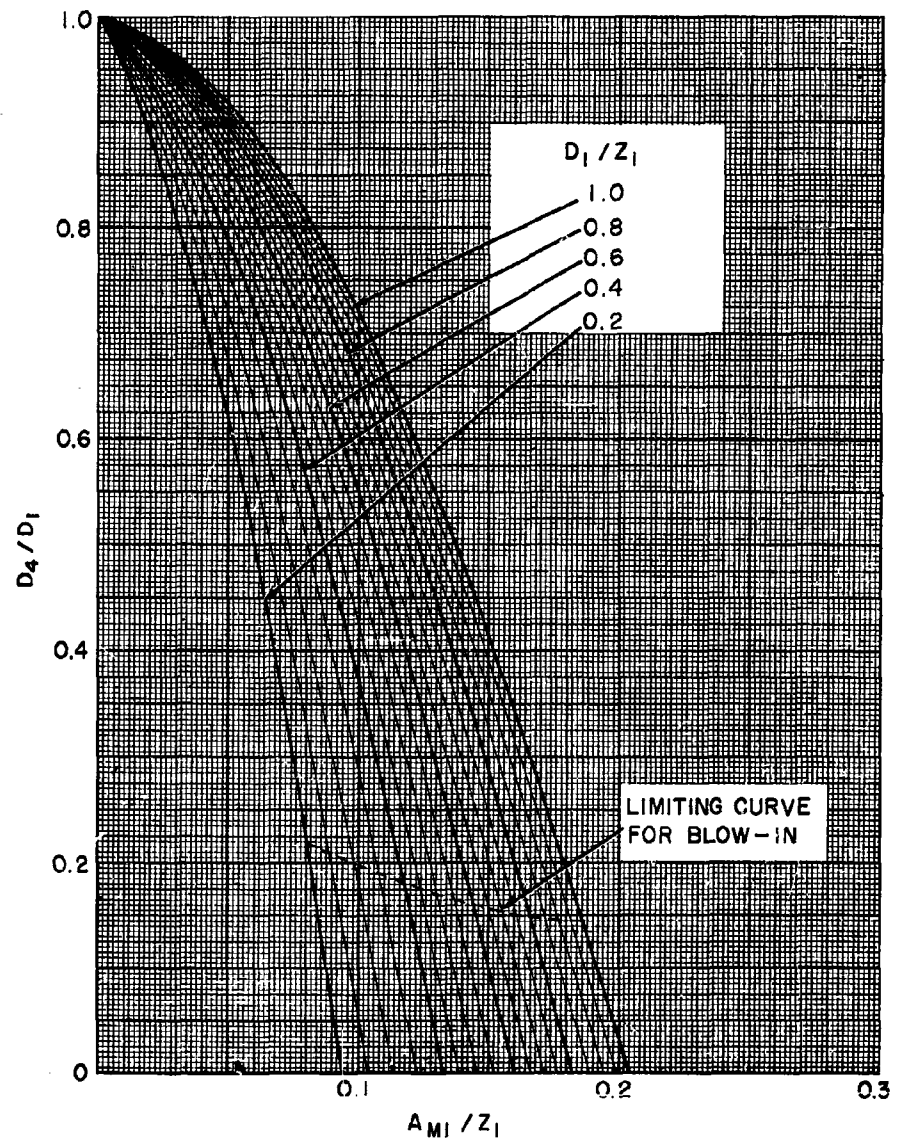
FIG. 3 RELATIVE DEPTH AT FOURTH BUBBLE MAXIMUM
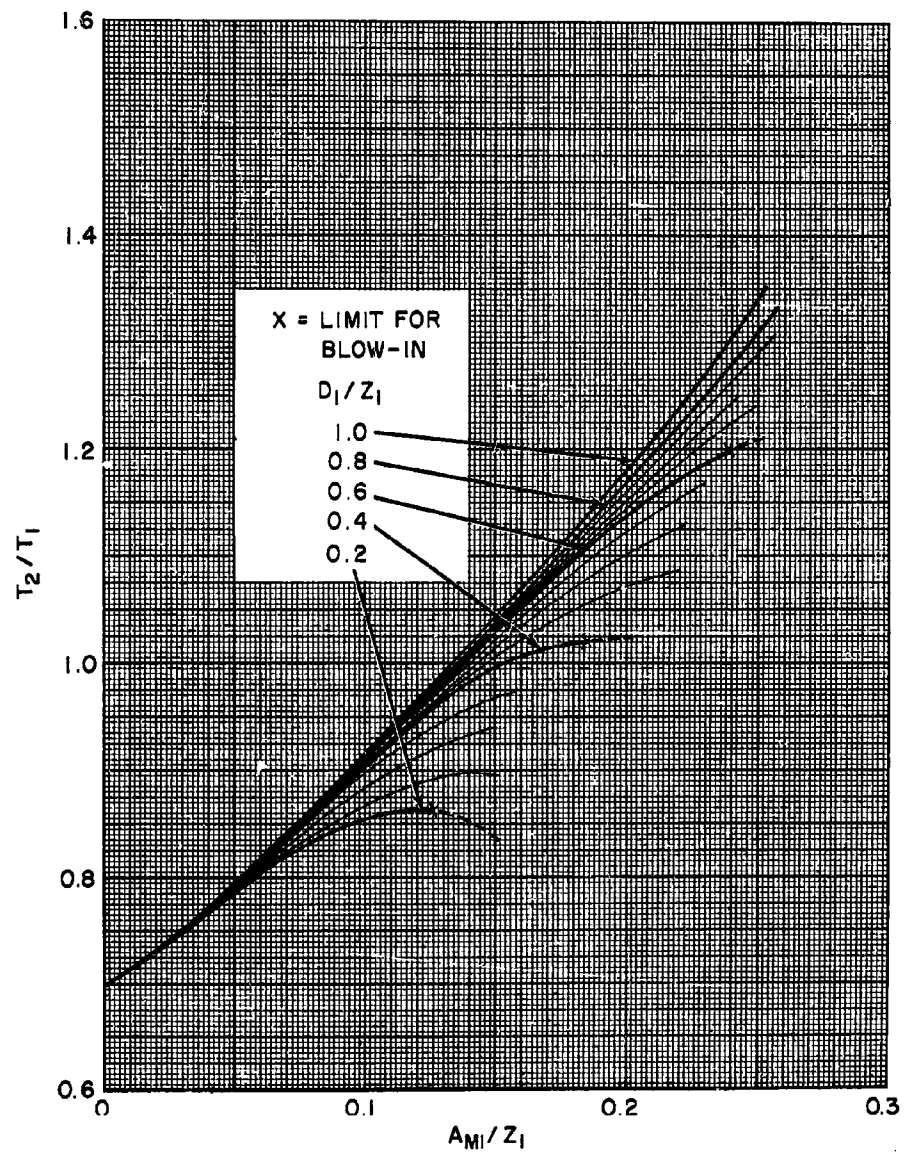
FIG. 4   RELATIVE SECOND BUBBLE PERIOD
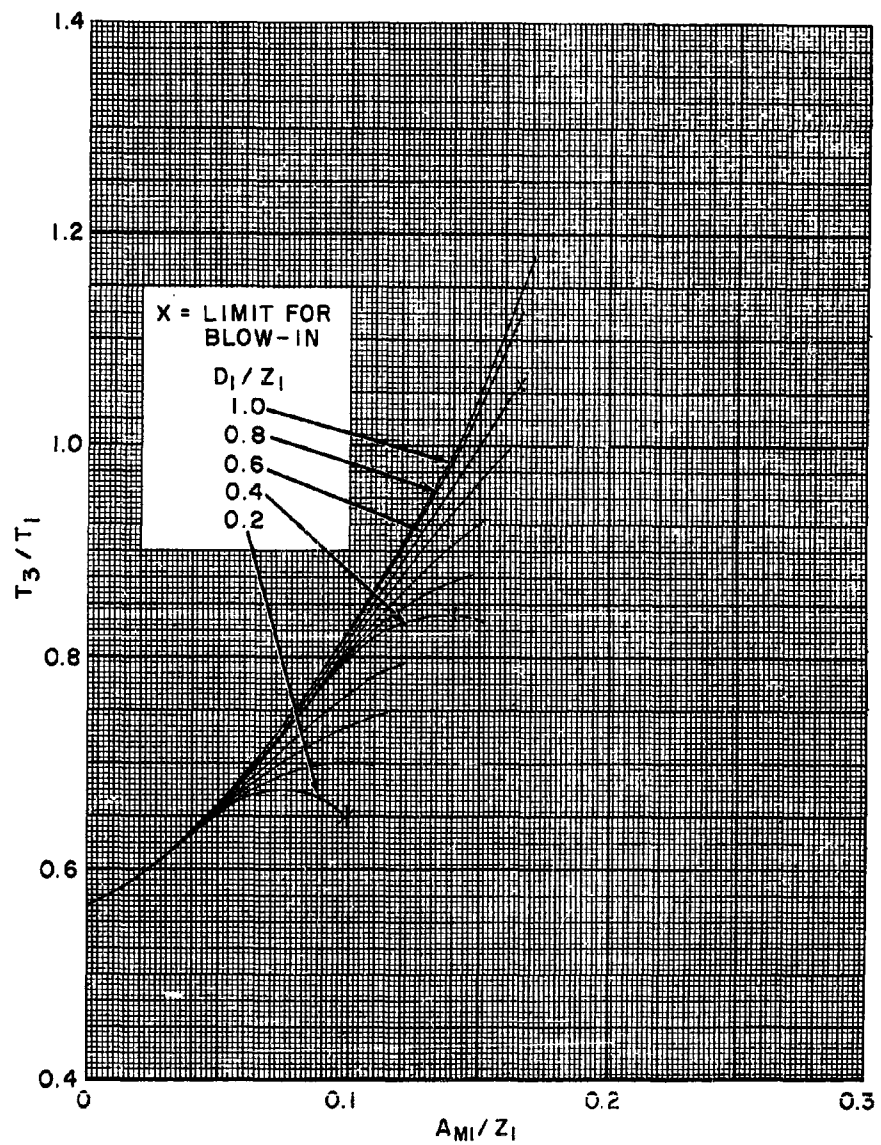
FIG. 5 RELATIVE THIRD BUBBLE PERIOD
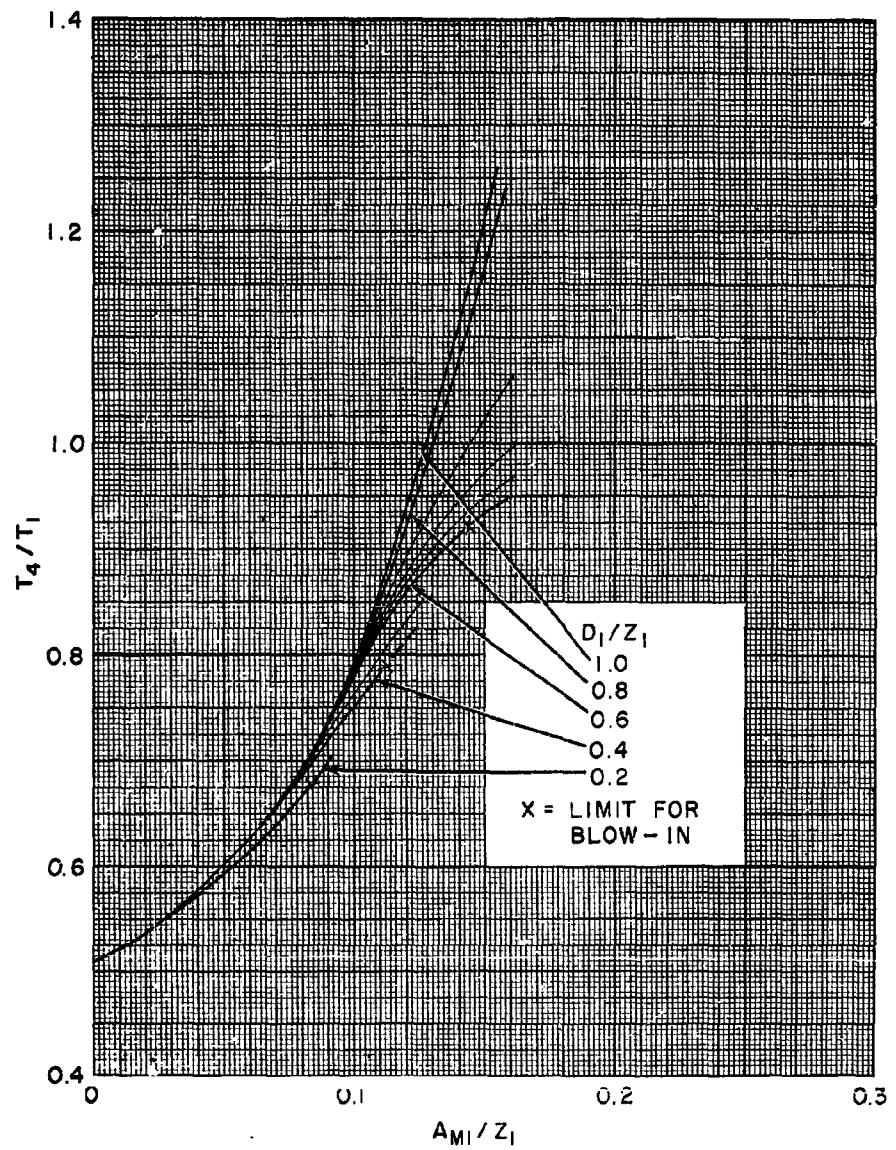
FIG. 6   RELATIVE FOURTH BUBBLE PERIOD
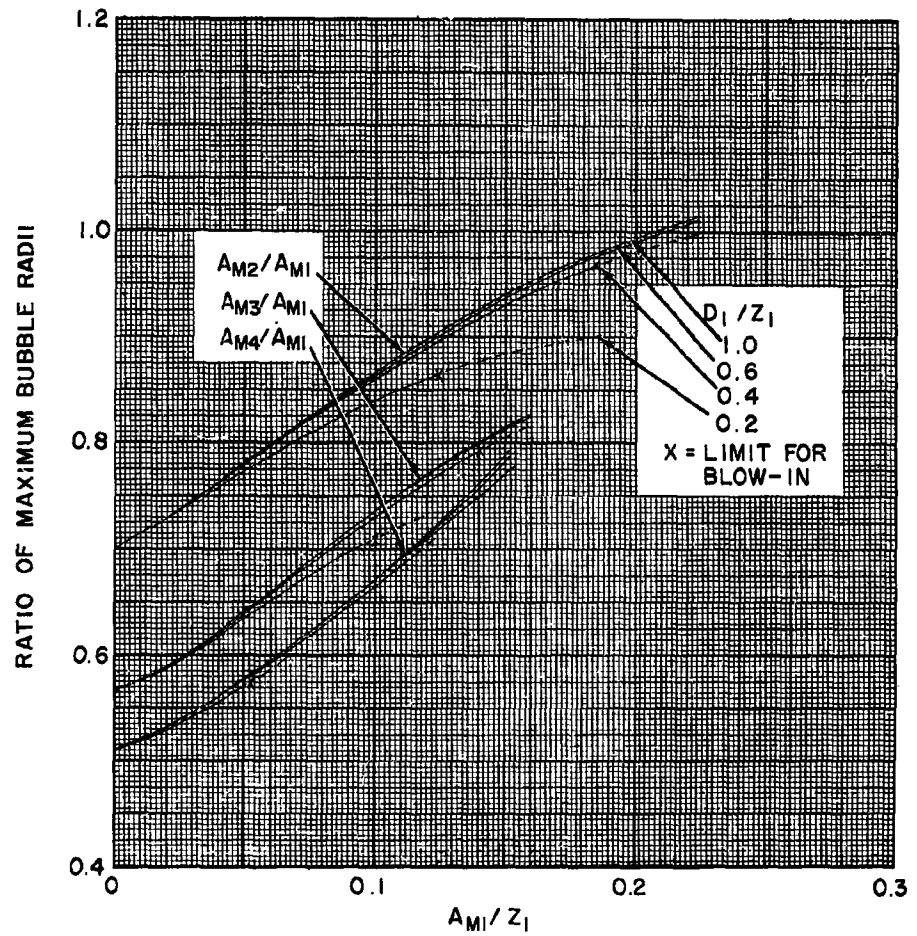
FIG. 7 RELATIVE MAXIMUM BUBBLE RADII

D_1/Z_1 LABELS ARE ONLY SHOWN FOR THE
UPPER FAMILY OF CURVES. LABELS FOR THE
OTHER CURVES ARE ANALOGOUS
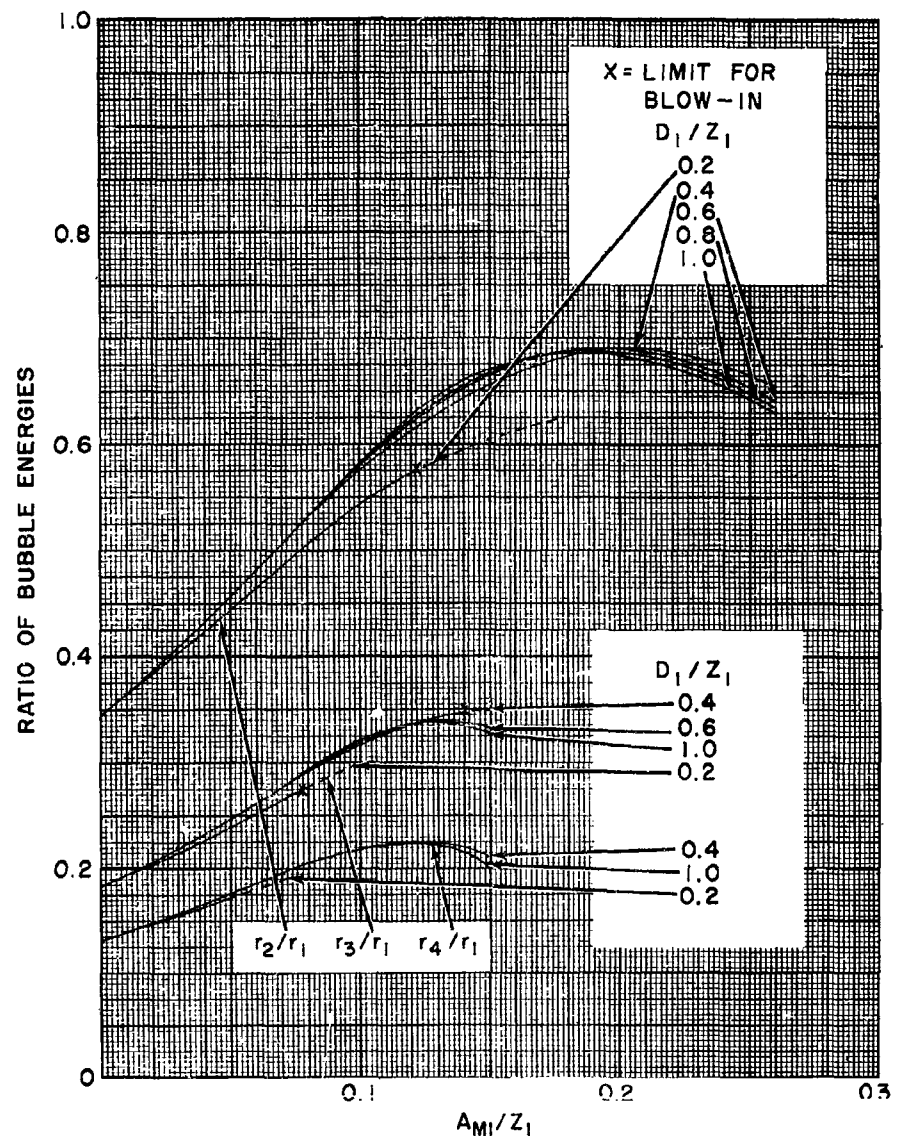
FIG. 8   RELATIVE BUBBLE ENERGIES

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(a) "Underwater Explosion Phenomena: The Parameters of Migrating Bubbles", H. G. Snay, NavOrd Report 4185, 12 October 1962, Unclassified.

(b) "Underwater Explosions. A summary of Results", E. H. Kennard, DTMB Report C-334, February 1951, Confidential.

(c) "Explosion Effects Data Sheets", NavOrd Report 2986, 14 June 1955, Confidential.

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DESCRIPTORS	CODES	DESCRIPTORS	CODES	DESCRIPTORS	CODES
Charts	CHRS	Cycles	CYCE		
Migrating	MIGR	Oscillation	OSCA		
Explosion	EXPS	Position	POSO		
Bubbles	BUBB	Computation	COMA		
Parameters	PARA	Gas	GASE		
Underwater	UNDE	Bubbles (behavior)	BUBBZ		
Energies	ENER	Equations	EQUA		
Maximum	MAXM	Numerical	NUMB		
Minimum	MINM	Dependency	DEPN		
Radii	RAUS	Water	WATR		
Periods	DURT	Surface	SURA		
Four	FOUT	Phenomena	PHEO		

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3. Bubbles - Migration
4. Bubbles - Measurement
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2. Bubbles,
    Explosion
3. Bubbles –
    Migration
4. Bubbles –
    Measurement
    Title
I. Snay, Hans G.
II. Tipton, Ruth
III. V., jt. author
IV. Project
V. Project